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16. Abstract Reaction times to stimuli were measured using simple apparatus in the upper arm, index finger and retina. It is found that reduced reaction times are not noticeably different for various parts of the body. In the case of the eye, the reaction times are similar to other functions. Therefore, the reaction method cannot be used to determine the sensible and motor conduction velocity and at the present time, the conduction velocity in the long paths of the spine are unknown.

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THE DEPENDENCE OF REACTION TIMES ON THE LOCATION OF THE STIMULUS*

G. S. Hall and J. V. Kries

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The propagation velocity of excitation in sensitive nerves has been repeatedly determined by assuming that the difference in reaction times for stimulation of skin locations located at different distances from the center are a measure for the reaction times. As is well known, this method is only correct if it can be shown that the part of the reaction time which cannot be attributed to conduction in the peripheral nerves and in the long paths of the spine is the same, as well as the latent time in the perversed sensory organ and reacting muscle. In other words it has to be assumed that the reduced reaction time is the same in all cases. In many earlier investigations of this subject, this assumption was usually made and sometimes stated. The values obtained using this assumption were not very satisfactory, however. They fluctuated between 26 meters per second (Schelske) up to 225 meters (Kohlrausch), that is, almost by a ratio of 1:9.

Donders [1] first postulated that this assumption was not correct, based on a comparison of the sensitive conduction

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* From the Physiological Institute in Leipzig, Germany.

** Numbers in margin indicate pagination in original foreign text.

velocity and the motor velocity excluding the central organ. On page 662, Donders states, "These direct determinations have made obsolete all the experiments with sensory nerves in which the brain activity was included. It is now known what this means. Wittich/2 would very much like the velocity for the sensory nerves to remain in effect. However, this is impossible; the agreement between the sensory nerves and the motion nerves is too close in all respects so that it is now impossible to still accept these conduction velocities found according to doubtful methods. This is true because of the great certainty associated with our determinations."*

At this point the question could have been assumed to be settled. However, in 1870 Helmholtz and Baxt reported about new determinations for the motor nerves, and they showed the great dependence of the conduction velocity on temperature. Therefore, the statements by Donders seem to have lost some of their validity. In fact, several researchers have again used the old assumption again since that time. Exner used this assumption [2] to determine the velocity of the sensitive and motor conductive paths in the spine. Bloch and Garver found it impossible to determine the conduction velocity with this method. Richet [3] recently again assumed that the reduced reaction times are independent. (See the remark at the end of the paper).

Two problems arose during the further investigation of the question. First of all it was necessary to again determine whether the reduced reaction times are substantially different; secondly, assuming this to be the case, it had to be determined on what these differences depend. Up to the present, these differences were only looked upon as an error source which could not be determined. We believe it is now necessary to publish our findings because our knowledge regarding this question has been somewhat expanded because of a limited number of experiments.

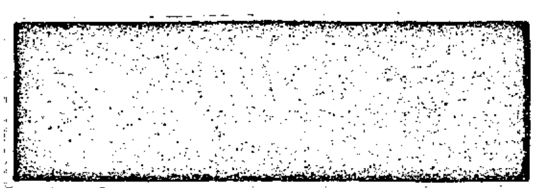
* The determinations were published by Helmholtz and Baxt in 1867.

We do not intend to use skin stimuli like the earlier experimenters, but instead we will use optical stimuli. The method in our experiments will be briefly described, in spite of the fact that other methods have been designed for the same purpose. This is because our methods are very convenient and safe.

Each experiment was recorded graphically on the drum of a Baltzar kymographion which was set at its maximum velocity. /3 Since the turning rate of the drum cannot be assumed to be constant, unless special measures are taken, we also use a recording tuning fork with 29 oscillations per second to record the time.

1. We mark the stimulus as follows: One arm of the tuning fork was pulled out of its equilibrium position using an electrical magnet. It then touches the armature of the electrical magnet and is held there by the electromagnet. We will call the current circuit through the electrical magnet the interruption circuit. It can be opened at any time with a key by the observer. By opening the key, the tuning fork is pulled away from the armature and starts oscillating. When the tuning fork arm contacts the armature, a second circuit closes, which we will call the stimulation circuit. When the tuning fork pulls away from the armature, the stimulation circuit is interrupted. This circuit passes either through the primary winding of a du Bois device or through a Ruhmkorff induction apparatus. This means that the beginning of the tuning fork oscillations coincide in time with the induction pulse or induction spark, which is used as the sensory or visual stimulus.

2. The reaction consisted of finger pressure, which interrupts a third current circuit, the reaction circuit, using an easily moveable lever. The interruption is recorded without any time retardation by means of a small Marey electrical magnet, the recording pen of which is below the recording pen of the tuning fork. This means that any individual experiment is carried out as follows: The interruption circuit is opened, the stimulus circuit is opened, stimulus, reaction, consisting in the opening of the reaction circuit. The image obtained from such an experiment is as follows:



ab is the reaction time. When the observer leaves the interruption circuit open for only a short time, the tuning fork will each time no longer carry out very many oscillations as is required for determining the time of the corresponding reaction, because it is very soon again held fixed by the armature of the electrical magnet. This means that it is possible to carry out about 10 experiments in sequence without displacing the drum. This means that many experiments can be carried out very rapidly using the method, and the manipulations of the observer are at a minimum. Also there is only a very slight disturbance to the reacting person. The measurement of the reaction time can easily be done up to an accuracy of 1/10 of the tuning fork oscillations. This accuracy is completely sufficient considering the differences / 4
in the individual values.

The experiments were usually carried out by carrying out a test series of one type in between two test series of the other type. The differences between the former and the arithmetic mean of the latter two then resulted in the desired value.

The influence of fatigue is eliminated as much as possible in this way. The test series which are related in this way will be called a group in the following.

I.

The intensities of the induction process used as sensory stimuli were quite strong, but they did not produce pain. It is remarkable that it cannot be determined how the pulses for two different skin locations should be made "subjectively equally strong". For example, a very strong touch sensation can be produced in a finger, which for this reason will not yet be painful. This is not at all possible in the upper arm. In the upper arm, there is a stinging sensation as soon as the sensory sensation becomes strong, which is not at all present in a finger. Therefore, it is impossible to make the stimulus the same for two so different locations, because the various sensation qualities are not functionally connected in the same way. In addition, this point is not to be overestimated, because the dependence of the reaction time on the stimulus intensity is quite small within rather wide limits [4].

The following tables first give a comparison between the stimulus of the index finger tip and a point on the upper arm, which approximately corresponds to the insertion of the deltoideus. We will restrict ourselves to giving the results as found in each group using the method mentioned above. /5

Let us assume that the two skin points are separated by 65 cm and that the conduction velocity is 60 meters, a very large number. This means that one would have to expect a time difference of +0.011 sec. In contrast to this, we find that the difference is 0.003 for subject K., a conduction velocity of 214 meters.

TABLE I. STIMULATED LOCATIONS: TIP OF THE INDEX FINGER AND CENTER OF UPPER ARM. REACTION TIME IN UNITS OF TUNING FORK OSCILLATIONS = 1/29 SEC.

	Reaction of H			Reaction of K		
	Arm	Finger	Difference	Arm	Finger	Difference
	4.85	4.81	−0.04	3.94	3.86	−0.08
	4.43	4.16	−0.27	3.49	3.80	+0.31
	4.48	4.47	−0.01	3.69	3.78	+0.09
	4.12	4.16	+0.04	3.77	3.73	−0.04
	4.83	4.72	−0.09	3.84	3.89	+0.05
	4.10	4.05	−0.05	3.76	3.76	0.0
	4.12	4.03	−0.09	3.84	3.56	−0.28
	4.13	4.03	−0.10	3.52	3.78	+0.26
	4.32	4.22	−0.10	3.47	3.67	+0.20
	4.41	4.19	−0.22	3.37	3.72	+0.35
	4.63	4.24	−0.39	3.46	3.60	+0.14
	4.37	4.21	−0.15	3.49	3.61	+0.12
Avg.	4.40	4.27	−0.13	3.64	3.74	+0.10
In Sec.	0.152	0.147	−0.005	0.126	0.129	+0.003

However, the results obtained using the subject H are completely decisive. The reaction time from the upper arm is always longer than from the finger, in spite of the shorter conduction path. Of the 12 individual values found for the difference, only one is positive. Certainly anyone will have difficulty in attributing this state of affairs to the conduction velocities. For this purpose one would have to make the improbable assumption that it depends on the length of the path which it traverses. It would have to be assumed that it is different in various parts of the nerves, etc. Absolutely no objections can be made to the most natural interpretation which is that the reduced reaction time depends considerably on the location of the stimulated points, in a manner such that they are shorter when the finger is stimulated than when the arm is stimulated. In the case under consideration, this difference must have amounted to 0.011 + 0.005 = 0.016 sec. This difference is not even important compared with the entire magnitude of the reduced reaction time. If we assume that the /6 conduction length from the finger to the cerebral cortex is about one meter, we obtain a round trip conduction time of 0.033 sec., assuming a velocity of 60 meters. If we also add 0.010 sec. as the latent time in the muscle and subtract 0.043 from the total reaction time 0.147, we find that the reduced time is 0.104. The corresponding value for the upper arm is 0.104 + 0.016, that is, only 1/6-1/7 more.

In a certain sense we believe that it is a fortunate coincidence that the difference in the reduced reaction times is so great when the locations are compared, because the conduction time differences are overcompensated for in this way. Even though we investigated a number of other locations, we never again found such conditions. However, even a single case is enough to prove that differences in reduced reaction times do exist.

We obtained the following average value from seven groups in a comparison of reaction times of the finger and the neck:

H.			K.		
Finger	Neck	Difference	Finger	Neck	Difference
0.150	0.142	0.008	0.126	0.120	0.006

The difference in the reduced reaction times is only effective here because it reduces the differences which result from the conduction paths. Therefore, one would obtain values which would be too high (120 and 150 meters) when the conduction velocity is calculated.

II.

When we investigated the eye we found quite similar conditions, but even more pronounced. Here we are dealing with a comparison of the reaction times for a light signal seen directly and indirectly. We did not use the induction spark passing through the air, but we allowed the pulse to discharge through a small Geissler tube. This had two advantages: first of all a higher intensity of the light phenomenon and secondly there was no noise. (As is well known, the light signal cannot be an acoustic signal at the same time). A simple holding device was used to hold the head of the observer in the same position. (However, rotations are allowed). The light signal did remain at the same location, but the eye could be directed towards various visual points, so that the light phenomenon could either be located at the fixation point or at various points of the edge of the field of view. The same eye was always used and the other was closed.

/7

Here we could have also imposed the condition of making the stimuli of equal intensity for various parts of the retina. However, the behavior of the various parts of the retina is not yet clarified and we therefore preferred to let the same stimulus act upon all of the parts. As will immediately be shown, the results we obtained are so clear that they would not have been influenced at all by considerable variations in the intensities.

TABLE II. COMPARISON OF REACTION TIMES FOR DIRECT AND INDIRECT OBSERVATION OF THE LIGHT SIGNAL. THE POINTS FOR INDIRECT VISIBILITY ARE SEPARATED BY 30° FROM THE FIXATION POINT. THE NUMBERS REFER TO TUNING FORK OSCILLATIONS OF 1/29 SEC.

Reaction of H

	Direct	Outside	Inside	Direct	Below	Above
	6·33	7·43	7·60	6·18	6·76	8·30
	5·66	6·63	7·15	5·91	6·52	7·85
	6·15	7·24	7·41	6·37	6·99	8·11
	6·58	6·71	7·83	6·51	7·67	8·10
	7·07	8·35	790	7·24	8·04	9·27
Avg.	6·36	7·11	7·58	6·44	7·20	8·33
In Sec.	0·219	0·245	0·261	0·222	0·248	0·287

Reaction of K

	Direct	Outside	Inside	Direct	Below	Above
	4·80	5·38	5·45	4·64	5·07	6·00
	5·17	5·66	5·90	5·08	5·70	6·51
	4·66	5·16	5·33	4·79	5·51	6·11
	4·85	5·33	5·88	5·66	5·49	6.22
	5·22	5·58	5·64	5·13	5·40	6·17
	4·92	5·19	5·83	4·99	5·18	6·45
Avg	4·94	5·38	5·67	4·95	5·39	6·24
In Sec.	0·170	0·186	0·196	0·171	0·186	0·215

In the following we will designate the test series according to the point of the visual field of view at which the light signal appears. For example "outside" refers to the fact that it was located in the temporal half of the field of view and therefore the medial retina was involved. Here again the test series were arranged in groups according to type, so that fatigue could be eliminated, for example.

1) Outside, 2) Inside, 3) Outside, for comparison of these two field of viewpoints; or

1) Direct, 2) Outside, 3) Inside, 4) Outside, 5) Direct, in which 3) is compared with the average value of 1) and 5) and 2) and 4). The average values given in the following should be evaluated according to this fact.

These tables represent evidence for the fact that the /8
reaction times are greater for indirect vision than for direct vision. However, it is also seen that the direction, which is separated from the fixation point by a certain number of degrees, is not at all unimportant.

/9

The values for the lower and upper part of the field of view are almost the same. However, the value for the medial path is always greater than for the temporal half, and it is greater for the upper half than for the lower half. Perhaps it seems somewhat possible to relate these very considerable differences to conduction times in the peripheral nerve fibers. However, it is much more likely that the idea, according to which the central parts of the reaction times are different depending on the stimulus location, applies here. It is interesting to note that we find a very clear relationship with other functional differences in the parts of the retina. In fact, we do know that all types of functional capacities of the retina (sharpness of vision, optical sensation and color sensation) decrease rapidly in various directions from the center, so that if the angular separation is the same, the temporal half of the field of view is always preferred over the medial half, and the lower half is preferred over the upper half. Usually this is attributed to the fact that we are more accustomed to observing the lower half of our visual field of view than the upper half. Also, each eye is assigned the task of observing the side parts of the field of view on its side (the right eye observes the side region on the right and the left eye observes the side region on the left). We do not think it is too bold to assume that the reaction times also depend on the amount of practice that the individual retina points obtain. The same point of view can also be used to easily explain the particularly short reaction times when the fingertips are stimulated. However, it does not follow from this that there is a close dependence between the reaction time and the space sensation, according to which the parts having the finer space sensation will always have the shorter (reduced) reaction time. For example, when we compared the tip of the tongue with the forehead, we obtain the following average value from eight groups:

K.		H.	
Forehead	Tongue	Forehead	Tongue
0.122	0.126	0.163	0.166

This means that the reaction time from the tongue is somewhat longer than from the forehead, even though according to Weber the space sensation is finer by about a factor of 20 than at the forehead. Also the conduction times for both points can only produce a very small difference. We were not able to establish any difference between the dorsal and volar side of the last phalanx of the finger.

TABLE III. COMPARISON OF REACTION TIMES FOR DIRECT AND INDIRECT OBSERVATION OF THE LIGHT SIGNAL. THE POINTS FOR INDIRECT VISIBILITY ARE SEPARATED BY 60° FROM THE FIXATION POINT. THE NUMBERS REFER TO TUNING FORK OSCILLATIONS OF 1/29 SEC.

Reaction of H.

	Below	Above	Difference	Outside	Inside	Difference
	8·08	9·04	0·96	8·40	7·72	0·32
	7·48	8·33	0·85	7·89	8·72	0·83
	7·90	8·05	0·15	6·98	7·82	0·84
	7·05	8·30	1·25	7·69	8·08	0·39
				8·16	8·44	0·28
Avg.	7.63	8·43	0·80	7·62	8·16	0·54
In Sec.	0·263	0·291	0·028	0·263	0·281	0·018

Reaction of K

	Below	Above	Difference	Outside	Inside	Difference
	5·72	8·04	2·32	6·36	7·28	0·92
	5·24	7·10	1·86	6·14	6·78	9·64
	5·07	6·40	1·38			
Avg.	0·34	7·18	1·84	6·25	7·03	0·78
In Sec.	0·184	0·248	0·064	0·216	0·277	0·061

Therefore, we do not postulate a simple and generally valid dependence between the sensitivity and the reaction time. Instead we only are postulating the unquestionable relationships which can appear under certain conditions. /10

It is true that the training of the point which is stimulated does have an influence on the reaction time which cannot be ignored. However, we should expect that the type of reaction is also important. Many motions which we are used to carrying out with precision and at will can be performed more rapidly than other types of motions. Accordingly, the determination of the motor conduction velocities from the reaction times can be criticized in the same way as the sensible ones. If we consider the fact that the determination of the sensible and motor conduction paths within the paths of the spine is based on a comparison of the reaction times when the upper and lower extremities are stimulated or when there are reactions with either one, we find that the conditions mentioned above lead us to the conclusion that the conduction in the spine is slower than is actually the case. A large part of the delay which occurs when the lower extremity is used is erroneously attributed to the conductor in the spine.

The results given above can be summarized by stating that the reduced reaction times are not noticeably different depending on the point where the stimulus is applied. In the case of the eye, these differences are very clearly correlated with the differences for other functional capacities of the various parts of the retina. The fact that the reaction method cannot be used for determining the sensible and motor conduction velocity leads us to the conclusion that the conduction velocity in the long paths of the spine is unknown at the present time.

Remarks:

When we consider the differences in the reduced reaction times, we can automatically eliminate one reservation put forth by Richet (l.c.) in the discussion of the paper written by myself and Auerbach. He asks whether the order of magnitude of the time differences (1-6 hundredths of a second) do not lie within the experimental error. He even believes this is likely because of his own experiments. These experiments consisted of determining the sensible conduction velocity using the reaction method, and he was not successful. Rechet completely ignored the possibility of a difference in the reduced reaction times, as he states in his own words. Because of this fact we believe that he failed in his efforts, and not because of the low accuracy in the experiments. (Kr.)

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